RADIO PROPAGATION OVER TERRAIN

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ABSTRACT

A completely new propagation assessment system called Radio Propagation Over Terrain (RPOT) is presented. This system is designed for PC platforms using the Windows 95 operating system. The internal propagation model is a combination of the Terrain Parabolic Equation Model (TPEM) and the Radio Physical Optics (RPO) model, which allows for range-dependent refractivity variations over terrain or sea paths.

RPOT computes and displays radar probability of detection and/or Electronic Support Measure (ESM) vulnerability or communications capability versus range, height, and bearing from the source. Refractivity data can be entered using several methods, including a filly automated decoding of common World Meteorological Organization (WMO) codes already available on many local area networks. For each bearing, terrain elevation data are automatically extracted from the National Imaging and Mapping Agency (NIMA, formerly the Defense Mapping Agency, DMA) Digital Terrain Elevation Data (DTED), supplied on CD-ROMs. Coverage diagrams are computed and stored as graphics files for each bearing desired, and then displayed in rapid sequence as either full 360 degree rotations or as sector scans.

Both RPO and TPEM have been developed in parallel at NCCOSC RDTE DIV (NRaD) and until recently have remained as two completely separate models. RPO is an efficient ray-optics and parabolic equation (PE) hybrid model for all over-water paths. TPEM began as a pure PE model for terrain paths, but recent versions also employ hybrid models. An effort to consolidate RPO and TPEM into one single model that includes the capabilities of both will be described. The combined model computes propagation loss versus height and range for range-dependent refractivity over smooth and variable terrain, also accounting for variable antenna patterns and range-varying dielectric properties of the ground.

The power of RPOT derives from its user interface as well as the modem high-fidelity propagation models. RPOT is a Windows 95 application, making fill use of drop-down menus, on-line help, and other standard Windows features to make a fully integrated and user friendly propagation assessment system.

BACKGROUND

The Office of Naval Research maintains a book titled “Technologies for Rapid Response” that lists technologies under current development that could be accelerated into operational capabilities in 6 to 12 months, provided there was a strong operational need for them. In 1995 our group submitted *one* such technology description to this book with the title “Radar Propagation Over Terrain” (RPOT) based on the Terrain Parabolic Equation Model (TPEM) that was under development at NRaD. The following is an excerpt from that description. “This capability provides the ability to assess shipboard radar coverage over water, across coastlines, and over varying terrain in range-dependent refractive environments. Required inputs include digital terrain elevation data, refractive structure, and radar parameters. Output would be radar detection probability contours in a vertical cross-section versus azimuth, taking first-order effects of terrain into account .“ In late 1995 the Commander, Sixth Fleet staff expressed a serious interest in developing the RPOT capability to support Sixth Fleet ships and aircraft operating in the Adriatic in support of the Bosnia peace mission. At the same time a new ONR program called the Naval Technology Insertion Program (NTIP) was preparing to find some of the technologies listed in the book. In early FY96 the final decision was made to find the RPOT effort under the NTIP program with the goal of providing the final system to Sixth Fleet forces by June 1996.

In early FY96 TPEM was already developed to the point that radar coverage diagrams could be produced based on terrain data read from the DTED Level 1 CD-ROMs (horizontal resolution of 3 arc seconds, about 100 m), and EM system and refractivity data read from special format ASCII files. TPEM at this time was a 32-bit DOS application developed with Microsoft Fortran Powerstation Version 1.0. Several other DOS programs had also been developed to support TPEM, for example to rapidly display a series of coverage diagrams versus bearing angle. Using these programs directly for operational support was deemed too impractical because of the time and training required for the operators to edit ASCII input files and use the programs in the proper sequence. A more user-friendly windows based user interface was required, and Microsoft Windows-95 and Fortran Powerstation 4.0 were selected as the host operating system and program development environment. The goal was to repackage TPEM into a user-friendly system that would use normal pull down menus and other Windows features, and to provide an easy interface to user-defined radar parameter libraries, DTED CD-ROMs, and existing meteorological data.

The Windows-95 RPOT assessment system was developed on schedule and delivered to the Sixth Fleet Flagship USS La Salle in June 1996. By this time, the Commander, Naval Meteorology and Oceanography Command (CNMOC) had asked the Space and Naval Warfare Systems Command (PMW-185) to make RPOT available fleet wide by August 1996. By August, a capability to assess radio communications coverage had been added to RPOT, and the name was changed slightly to Radio Propagation Over Terrain to better describe this addition. RPOT is now available fleet wide.

ASSESSMENT SYSTEM

This paper describes RPOT version 3.01. The minimum hardware requirements for RPOT are Windows-95 and a CD-ROM drive. In addition, we recommend a 100 MHz Pentium processor or better, at least 16 MB of RAM, a hard disk drive with at least one GB of free space, and an 800 by 600 resolution monitor. The RPOT software is distributed on either one CD-ROM, five high density 3.5 inch floppy disks, or via the internet. RPOT and all of its support files require about 8 MB of space on the PC's hard drive. Additional disk space is required to store the DTED files and graphics format files generated by RPOT for each bearing desired, plus other files generated for each project.

The user interface to RPOT is via pull-down menus and dialogue boxes that are similar to most Windows-95 applications. A project is defined as one or more vertical coverage diagrams for a radar or communications transmitter located at one geographic location. To generate a project, the user first fills in a project window to specify the radar, platform (such as a ship class), target, environment, latitude, longitude, initial bearing, bearing increment, and number of bearings desired, plus a few options to select the type of display, type of terrain area map, and propagation model desired. After entering all the required data in the project window, the user clicks on the "compute" button to begin all computations. The DTED manager first checks to see if all the required DTED files are already stored on the hard disk. If not, the user is provided with a list of required DTED CD-ROMs and is prompted to insert each one. After all of these files are loaded, the DTED manager will generate the terrain height profile along each bearing desired and TPEM or RPO will generate the corresponding coverage diagram. On a 100 MHz Pentium, TPEM will require about 15 seconds to a few minutes to compute a single coverage diagram, depending on frequency.

By default the propagation model automatically selects between RPO and TPEM. RPO is used for paths that are entirely over water if the transmitter or radar height is less than 100 m. TPEM is used for all other cases. However, the use of either TPEM or RPO exclusively may also be selected.

The DTED files are normally transferred from one or more CD-ROMs to the hard drive prior to their use by TPEM for two reasons. First, a hard disk drive has a much faster data transfer rate than the typical CD-ROM drive. Since most projects require multiple runs by TPEM from the same fixed location for multiple bearings, the same DTED files are typically accessed many times, and therefore the total file access time is reduced compared to reading the files always from a CD-ROM. Second, for projects that require 2, 3, or 4 DTED CD-ROMs due to the project's location near one or more boundaries between CD-ROMs, there is no need to load the same CD-ROMs over and over as RPOT generates the various coverage diagrams. However, for projects where all of the required terrain data are stored on one CD-ROM and the user does not have sufficient hard disk space, there is a provision where the terrain data can be read directly from the CD-ROM.

ENVIRONMENTAL INPUTS

RPOT provides several options for entering refractivity data. For many applications, the most useful method is to input the WMO significant level upper air radiosonde code (part UUBB or UUTT), which is widely available on many local area networks and in some cases available on the internet. RPOT can read an ASCII text file containing this code or use the windows clipboard feature to cut and paste the ASCII text from another windows application. RPOT can then automatically decode this text and create an environment file containing the modified refractivity versus height profile which is ready for use by the RPOT propagation models. If the sounding comes from a ship station, then by default an evaporation duct profile is appended to the radiosonde profile based on the assumption of a thermally neutral atmosphere, where the sea water temperature is assumed to be equal to the air temperature at the lowest measurement height. If this option is not desired by the user, it maybe turned off.

The user may also enter the refractivity profile, either as M or N units versus height in feet or meters, or in the form of pressure, temperature, and humidity. All commonly used units are provided for in this case.

RPOT also has a limited capability to accept range-dependent refractivity profiles. The propagation models are completely capable of using range-dependent refractivity, but RPOT has no method to change the environment from one azimuth to the next. Hence, one range-dependent environment can be defined that may be representative over a limited number of bearings, such as in a particular threat direction. This range-dependent environment must be created by the user with a text editor following a number of rules in combining profiles at different ranges. These rules are contained in the on-line RPOT help file.

PROPAGATION MODELS

The RPO propagation model is version 1.15 which is a fully accredited model in the Oceanographic and Atmospheric Master Library (OAML) maintained by CNMOC. RPO is a true hybrid method that uses the complimentary strengths of both Ray Optics (RO) and Parabolic Equation (PE) techniques to account for range-dependent vertical refractivity profiles. The RO techniques include full amplitude and integrated optical path length effects from refraction. The PE technique follows the method described by Dockery [1]. A brief description of the RPO models, and some comparisons to other models, are given by Hitney [2] and a complete description of the RPO model is given by Patterson and Hitney [3]. Two features of the PE model are real-valued sine Fast Fourier Transforms (FFTs) and variable transform sizes up to a maximum of only 1024 points. In comparisons of RPO to pure split-step PE models for stressful cases that are typical of those required for the Tactical Environmental Support System (TESS), RPO has proven to be from 25 to 100 times faster than the PE model alone, with overall accuracy at least as good as the pure PE models. In addition, RPO can solve problems for very high elevation angles, that PE methods alone cannot solve. RPO version 1.15 also includes models to account for tropospheric scatter and oxygen and water vapor absorption but these parts of the model are not used in RPOT.

The TPEM propagation model is version 1.5, which is a pure split-step PE propagation model capable of accounting for terrain and range-dependent refractivity effects. This model is not yet accredited in OAML, but it is in the process of being included. The model and its use are described by Barrios [4-6]. This model uses the discrete mixed Fourier transform method developed by Dockery and Kuttler [7] which allows for rigorous modeling of vertical polarization and finite conductivity. The model uses a numerical shortcut known as the "boundary shift" method to substantially reduce computation times. Although the model allows conductivity to vary with range, RPOT has no way to provide this information to the model. Since TPEM is a pure PE model, there is no limitation on source height, except as determined by the maximum transform siie, which allows for assessments of airborne systems up to the maximum altitude permitted by the frequency and transform siie. For UHF Airborne

Early Warning (AEW) radars, such as used on the E-2 aircraft, TPEM will typically allow assessments to be made at operational altitudes. For X-band radars, there will be significant height restrictions. TPEM only performs calculations below a predetermined maximum elevation angle that depends on source height and maximum output height and range. TPEM version 1.5 does not include either a troposcatter or an absorption model for oxygen and water vapor, but these capabilities are considered second or third order effects for most applications.

SAMPLE PRODUCTS

This section presents a selection of sample RPOT products to illustrate the various display options. These samples are all located in the Adriatic Sea and focus on paths toward and over Bosnia. In operation, RPOT displays coverage diagrams for a series of azimuths in a rapid sequence to form either sector scans or full rotational displays, which give very effective three dimensional assessments of coverage, but in this paper we can show only one azimuth at a time.

Figure 1 is a coverage diagram for a typical two-dimensional shipboard radar versus a small jet aircraft target. The colors (shades of gray in the figure) represent radar single-scan probability of detection (Pal) of the target. In this case, a strong surface based duct was assumed, which is evident in the diagram from the downward deflection of the region of high Pd just beyond the first several terrain features. Masking by the higher terrain features just beyond 50 nmi is clearly shown, as are the interference effects from the direct and sea-reflected paths. The white region at high angles is the region beyond the maximum elevation angle cut off for TPEM. The circular area map in the lower right corner is included to give the user a visual reference to the particular azimuth being displayed, which is indicated in the area map as a white line. Figure 2 is a coverage diagram for the same radar as figure 1, but here both radar detection and Electronic Support Measure (ESM) receiver counter detection are displayed together. Note the penetration by diffraction into the shadow region beyond the highest terrain features that allows an ESM receiver to detect the radar. Figure 3 illustrates the use of RPOT in assessing airborne radar coverage for a typical UHF AEW radar stationed at 18 thousand feet. This example assumed a strong elevated duct at 15 thousand feet, and the radar "hole" formed by this duct for ranges beyond 60 nmi is obvious in the figure. Figure 4 is a coverage diagram of ship-to-air UHF communications, and is displayed with just two colors representing the regions where communications is and is not possible. The conditions are the same as those for figure 1. Figure 5 is a refractive conditions summary that shows refractivity and modified refractivity in N and M units plotted versus height, and also indicates the heights corresponding to ducts. This display also indicates by color (not evident in the figure) what the refractive gradient is in each segment of the profile, and lists a numerical summary of the height of any ducts. This display is most useful to the operator in getting a quick look at the refractive conditions before generating any coverage diagrams.

COMBINED PROPAGATION MODEL

In developing RPOT it became clear that a new propagation model that combines the features of RPO and TPEM is needed. Such a model would eliminate the need to test for and switch between the two existing models, and also would fill in the high elevation angle region that is currently beyond the capability of TPEM. We intend to, call this new model the Advanced Propagation Model (APM) as a logical extension of the Standard Propagation Model that has long been included in OAML and was the propagation model used by the Integrated Refractive Effects Prediction System (IREPS). APM will be a hybrid RO and PE model similar to RPO in overall structure. It will account for terrain effects and range-dependent refractivity using the discrete Fourier transform split-step PE model from TPEM. Unlike RPO, it will not be restricted to source heights below 100 m and when fully developed it will include a tropospheric scatter model and oxygen and water vapor absorption model. We expect APM to be the propagation model used in the Advanced Refractive Effects Prediction System (AREPS), an application being developed for the Tactical Environmental Support System (Next Century) - TESS(NC).

SUMMARY

RPOT is a quick response development effort to support a Sixth Fleet specific requirement. In addition it provides a framework for the development of follow on assessment systems and propagation models. It provides a fleet wide assessment capability using modern high-fidelity propagation models that include terrain and refractive effects in a user friendly windows based environment.

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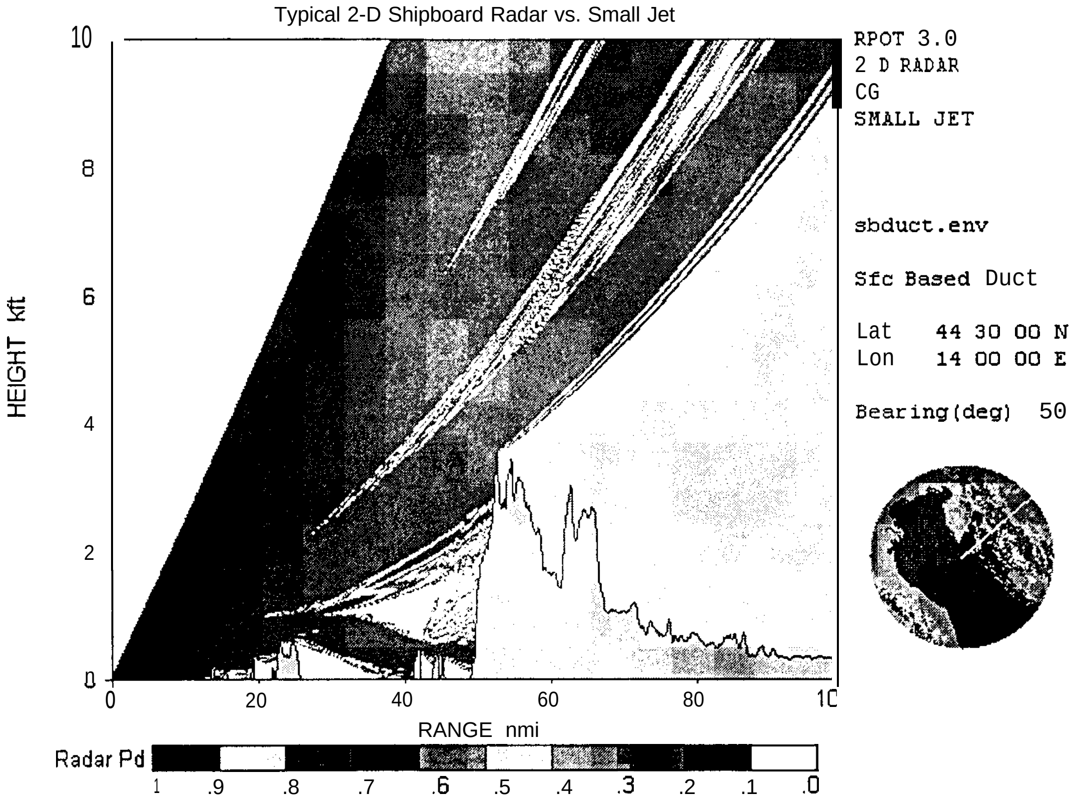

Figure I. Coverage diagram forashipboard radarversus asmall jet aircraft.

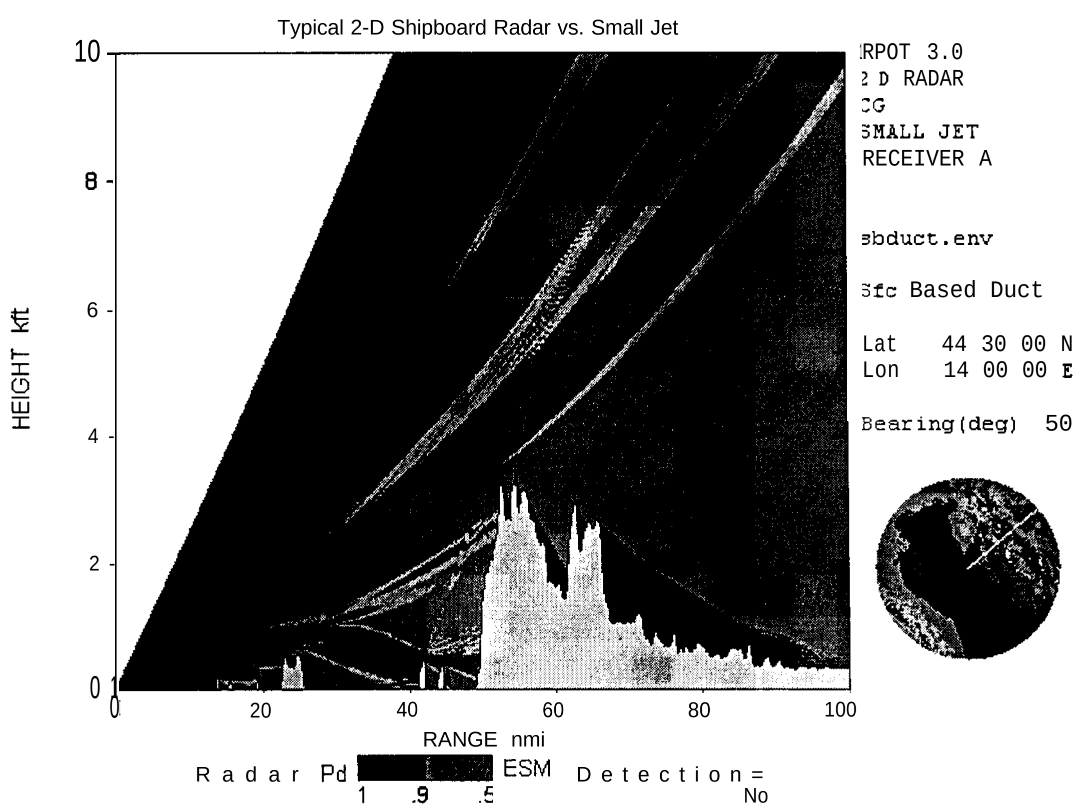

Figure2. Coverage diagram showing both radar detection and ESM vulnerability.

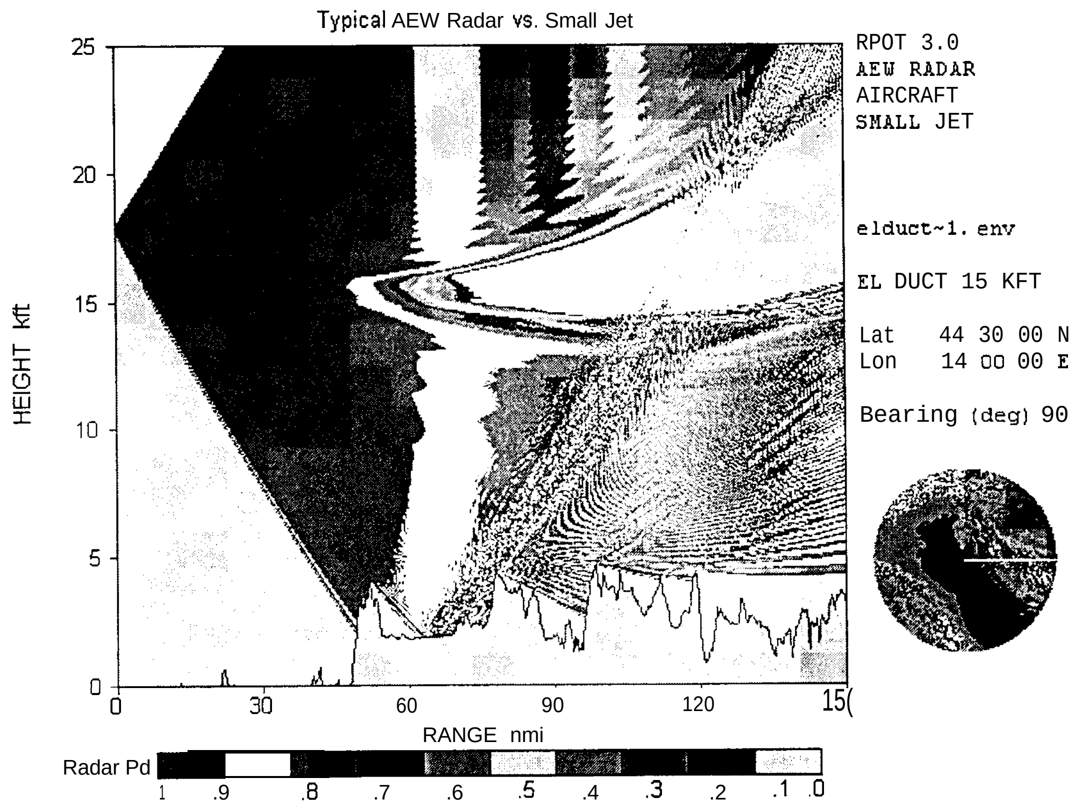

Figure 3. Coverage diagram for an airborne radar.

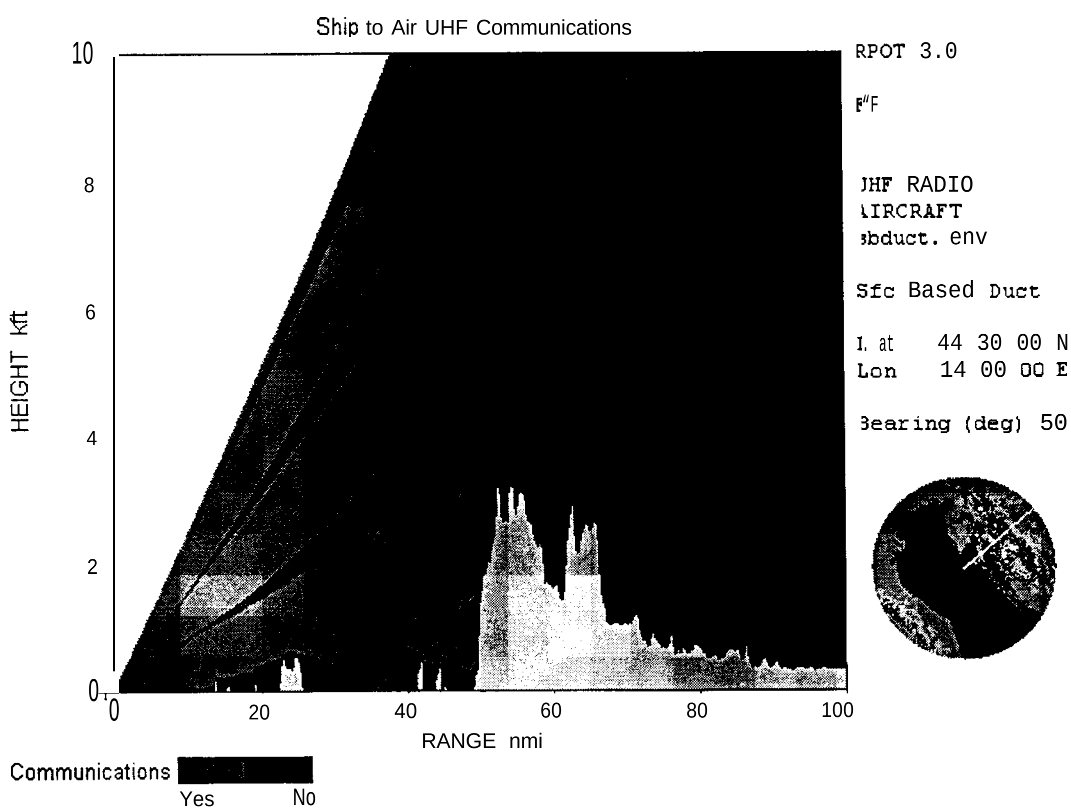

Figure 4. Coverage diagram for UHF communications.

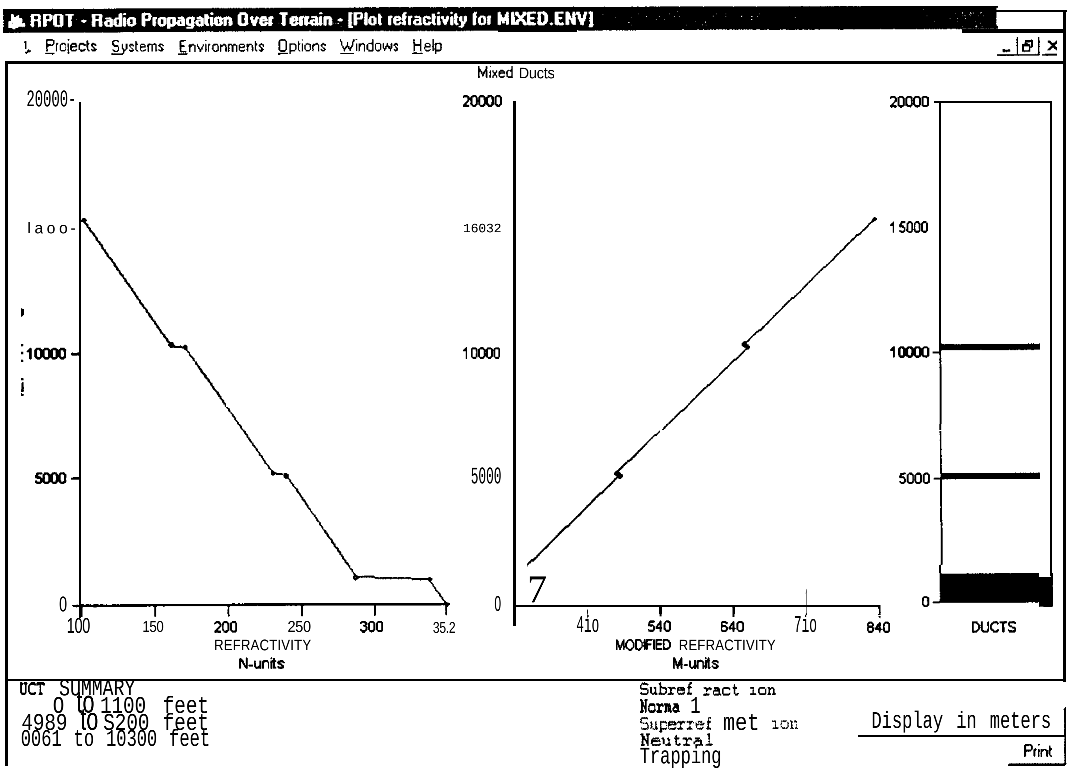

Figure 5. Refractive summary display.